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(54) An apparatus for removing gas from respiration air or for supplying gas to respiration air

(57) In an apparatus for removing gas from respiration air or for supplying gas to respiration air, comprising a respiration tube (4), a flowmeter (11) which is incorporated therein, and a container for gases which is connected to the respiration tube (4), it is proposed that the container is formed as a cylinder-and-piston arrangement (1, 2), a servomotor is provided for moving the piston (1), and a controller is provided for operating the servomotor, wherein operation is effected so that the velocity of the piston is proportional to the throughput measured by the flow meter (11).

Description

This invention relates to an apparatus for removing gas from respiration air or for supplying gas to respiration air, comprising a respiration tube, a flowmeter which is incorporated therein, and a container for gases which is connected to the respiration tube.

The capacity of a lung is determined by its efficacy for gas exchange, i.e. on the release of oxygen to the blood or on the absorption of carbon dioxide from the blood. Both these processes are dependent on a multiplicity of parameters, such as the volume of the lungs, the distribution of respiration air inside the lungs, the surface area of the alveolocapillary membrane and the thickness, diffusion properties or ventilation thereof. If any of these parameters differs from the norm, this can be a cause of pulmonary activity disorders.

In order to investigate such disorders, it is customary to analyse the composition of the exhalation air or to add defined additives to the inhalation air and then to measure the concentration thereof in the exhalation air. In the prior art, devices have been used for this purpose in which the patient exhales air through a respiration tube, which generally comprises a built-in flow meter, into a container which is connected thereto. The respiration air which is captured therein stems from one or more exhalation cycles. Analysis of the respiration air, even over one or more cycles only, therefore gives averaged readings.

Processes which occur during inhalation and exhalation and which proceed within a short time interval between the start and end of an inhalation or exhalation cycle, are also of particular medical interest, however. Analysis of these processes enables very complex research investigations to be performed on the causes of pulmonary diseases, and enables very precise therapy to be employed for lung function disorders.

The aforementioned devices are unsuitable for this purpose, however, since they do not permit removal of gas which is limited to short time intervals from the exhalation air.

Devices used for this particular application are generally based on the application of mass spectrometry, and necessitate very costly equipment. Devices of this type are therefore only

available to large research institutes and their use in routine investigations or in doctors' practices is ruled out for reasons of cost.

Against this background, the object of the present invention is to create an apparatus for removing gas from respiration air and for supplying gas to respiration air which enables an analysis to be made, using simple means, of the processes occurring between the start and end of a respiration cycle, and which is therefore suitable for being widely used.

This object is achieved according to the invention in that the container is formed as a cylinder-and-piston arrangement, a servomotor is provided for moving the piston and a controller is provided for operating the servomotor, and operation is effected so that the velocity of the piston is proportional to the throughput measured by the flowmeter (volume per unit time).

The proposed apparatus comprises a respiration tube, through one end of which the patient inhales and exhales, and the other end of which terminates in the ambient air. Therefore, as distinct from the prior art, exhalation and inhalation are not effected into a closed container or out of a closed container, but are always effected in communication with the ambient air. The essential elements of the apparatus, namely a flowmeter and a container which is formed as a cylinder-and-piston arrangement, are connected to the respiration tube. The cylinder connection is designed so that gas can flow from the respiration tube into the cylinder and conversely from the cylinder into the respiration tube.

The piston of the arrangement is driven by a servomotor. A controller is provided for operating the servomotor. The controller receives the values determined by the flowmeter and converts them into signals for the servomotor. According to one core concept of the invention, the servomotor is operated so that the velocity of the piston is proportional to the measured throughput in the respiration tube. Together with additional further developments of the invention, this design opens up numerous possibilities for the use of the apparatus according to the invention for performing complex investigations of pulmonary activity.

It follows from the proportionality of the piston velocity to the throughput in the respiration tube that the volume conveyed by the piston per unit time is proportional at any point in time

to the velocity of flow in the respiration tube. Since the velocity of the air in the respiration tube during inhalation and exhalation varies between zero and a maximum value, the velocity of the piston, and thus the volume conveyed per unit time, are subject to the same variations. This means that for a rapid respiration process the volume conveyed by the piston per second is large, whilst it is zero during a pause in respiration, and on the transition from exhalation to inhalation the piston changes its direction of movement.

When applied to the exhalation process, the servomotor is operated so that the piston executes a suction cycle. Part of the exhalation air which flows into the open air is thus removed via the connection between the cylinder and the respiration tube. Thus at any point in time the amount removed per unit time is proportional to the amount exhaled per unit time, i.e. to the throughput in the respiration tube. However, this means that at any point in time during the removal of gas the piston removes the same fraction from the amount exhaled per unit time. Thus the total amount removed corresponds to the same fraction of the total amount exhaled over the duration of the gas removal operation.

Analogous statements are applicable to an inhalation process. During inhalation, the piston executes an ejection cycle which can be used for supplying an additive gas to the inhalation air, via the connection between the cylinder and the respiration tube, for analysis purposes. At any point in time, the amount of gas supplied per unit time is proportional to the amount of inhalation air per unit time flowing into the respiration tube. However, this means that at any time during the supply of gas the gas which is supplied is admixed at a constant concentration with the respiration air. In the course of this procedure, the respiration air does not have to be removed from a closed vessel in which a gas mixture was previously prepared, as in the prior art, but can be continuously removed from the ambient air.

One embodiment of the apparatus according to the invention comprises a quite significant advantage. This design of the apparatus comprises a controller by means of which starting and finishing times of the piston stroke can be predetermined with respect to the start of inhalation or exhalation. Any predetermined values can be specified. According to one feature of the invention, starting and finishing times of the piston movements are of particular interest which comprise

a portion of the inhalation or exhalation cycle,
or exactly one inhalation or exhalation cycle,
or a plurality of inhalation or exhalation cycles.

The proposed apparatus thus enables access to be obtained to important medical topics in question which relate to processes during inhalation and exhalation which proceed in a short time interval between the start and end of an inhalation or exhalation cycle.

If an exhalation process is considered, for example, gas can be removed from the exhalation air in a simple manner, by specifying the corresponding starting and finishing times. Removal can be effected shortly after the start, at the maximum, or before the end of the exhalation process. The gas removal operations can just as accurately cover an inhalation or exhalation cycle, or if need be can also include the following cycles. It is therefore possible, by analysing the gas volume removed, both to investigate the change in composition of the inhalation air over a respiration interval and to follow the course of the composition from one respiration interval to the next.

Removal over a plurality of respiration cycles can be carried out so that each amount removed is itself analysed, or so that samples taken over the same time interval can be added cumulatively over the respiration cycles to form a resulting gas volume on which analysis is performed.

Analogously, additive gases can be admixed with the inhalation air during the inhalation process over a defined time interval, which is preferably selected so that it is shorter than the duration of inhalation. These intervals can either be arbitrarily predetermined over the inhalation cycle or can be repeated at arbitrary times during subsequent inhalation cycles. The gases which are inhaled in this manner can be detected again by the apparatus according to the invention in one of the subsequent exhalation cycles and information on lung activity can be obtained from the time of detection and from the amount detected.

The apparatus according to the invention therefore opens up a pathway for medical research in a field which was hitherto closed, and also opens up the possibility of investigations, which were hitherto not possible, in a doctor's practice. Of particular interest in this respect

are investigations of defined time intervals within the inhalation or exhalation cycle, and the determination of mean values which extend over one or more cycles. The apparatus according to the present invention makes it possible to make very precise measurements for both these types of investigation.

In a variant of this embodiment of the apparatus according to the invention, instead of the starting and finishing time of the piston stroke the starting time thereof with respect to the commencement of inhalation or exhalation and the volume conveyed by the piston are predetermined by the controller. In this embodiment, the piston only executes one outlet or inlet cycle over one or more inhalation or exhalation cycles, until the volume conveyed corresponds to that which is predetermined. Questions of this type are of interest when measuring the diffusion capacity of the lungs.

Gas is removed from the respiration tube by a suction cycle of the piston, and the supply of gas is effected by an ejection cycle of the piston. Thus the piston only moves during gas removal or gas feeding. At times in between, the piston is stationary and there is therefore no exchange of gas between the respiration tube and the cylinder at these times, even if the connection is open.

For more extensive investigations, however, the piston also has to be able to execute movements independently of any respiration activity. In one advantageous embodiment of the apparatus according to the invention, at least one valve is therefore provided between the cylinder and the respiration tube which enables or shuts off the flow between these two elements. The following valve positions are possible:

open during exhalation and closed during inhalation,
open during inhalation and closed during exhalation,
open during inhalation and open during exhalation,
closed during inhalation and closed during exhalation.

The first two settings are necessary when measurements are made over a plurality of respiration cycles using the present apparatus, and when it is either exhalation processes only or inhalation processes only which are to be studied. The last-mentioned setting is required if

the exhalation air which is aspirated by the piston is to be fed to an analysis instrument connected to the cylinder. The same setting is also necessary if a gas which is to be mixed with the inhalation air during a subsequent inhalation cycle is introduced into the cylinder from the outside. The valves are operated by the controller depending on the direction of movement of the piston.

Said valve control system affords the advantage that one and the same apparatus according to the present invention can be used both for the removal and subsequent analysis of gas from the exhalation air and for supplying of gas to the inhalation air. Moreover, this valve control system results in increased flexibility and reliability when carrying out investigations. Thus, for example, measurements can be made over plurality of exhalation cycles in a manner such that the piston is simply stopped during the inhalation phases situated therebetween. To reduce the risk of any uncontrolled exchange of gas, however, it is advisable if the valve between the exhalation tube and the cylinder is also closed during this period.

In one embodiment of the invention, in order to analyse the exhalation air conveyed by the piston a device for determining the gas composition is connected to the cylinder of the apparatus. Analyses such as these can provide information on pulmonary activity disorders.

Two categories of investigation are customary. In the first category, the composition of the exhalation air itself is analysed, and in the second category an additive gas is added to the inhalation air and the concentration of the additive gas in the exhalation air is then determined.

According to one feature of the invention, gases are added via a line which is connected to the respiration tube and/or to the cylinder and which comprises a valve by which flow can be enabled or shut off.

A medical topic of particular interest relates to the investigation of gas samples which are obtained over short intervals of time during one and the same respiration cycle. The analysis of gas samples such as these provides information on the change in gas composition during a respiration cycle. In one preferred embodiment of the apparatus according to the invention, investigations of this type are possible. This embodiment is distinguished by one or more

cylinder-and-piston arrangements which are connected to the respiration tube and which each comprise a servomotor for moving the piston. In investigations of this type, the individual pistons are operated in succession by the controller and the starting and finishing times for each of the various pistons are predetermined so that they fall within one respiration cycle. A sample of the exhalation air from one and the same respiration cycle is then taken by each cylinder-and-piston arrangement.

Other advantages, features and details of the invention are given in the following part of the description. In this part, an example of an embodiment of the apparatus according to the invention is explained in more detail with reference to the accompanying drawing.

The illustration of Figure 1 is a simplified section through the proposed apparatus.

In the drawing, the piston of the apparatus is denoted by reference numeral 1 and the cylinder is denoted by reference numeral 2. The piston is attached via a piston rod 3 to a servomotor, which is not illustrated, whilst the cylinder communicates with a respiration tube 4 via two connecting tubes. Connecting tube 5 is used during inhalation and connecting tube 6 is used during exhalation. The connection through these tubes can be opened or closed by a valve 7 or 8, respectively. One end 9 of the respiration tube leads to the patient's mouth, whilst the other end 10 is open to the ambient air. The respiration tube comprises a flowmeter which is denoted by reference numeral 11. Moreover, a line 12 via which additive gases can be admixed with the respiration air is connected to the respiration tube. This line can also be shut off by means of a valve 13. Further lines for the feeding and discharge of gases are also provided on the cylinder. Line 14 is employed for transferring the removed respiration air to an analysis instrument which is not illustrated, and line 15 is employed for mixing additive gases with the inhalation air. Both these lines can be shut off by means of a valve 16 and 17, respectively.

The velocity of flow in the respiration tube during exhalation is denoted by reference numeral 18, and that during inhalation is denoted by reference numeral 19. The velocity of the piston movement is predetermined so that it is proportional to these velocities. The result of this dependence of the piston velocity on the velocity of flow is that during a rapid respiration process the volume conveyed by the piston is large, and it is zero during a pause

in respiration; on the transition from exhalation to inhalation the direction of movement of the piston is changed. When the patient exhales, the piston 18′ executes a suction cycle and it therefore moves away from the cylinder base. Conversely, when the patient inhales the piston 19′ executes an ejection cycle and therefore moves towards the cylinder base.

By predetermining the starting and finishing point of the piston stroke by the controller, targeted sampling of gas from the respiration air, or the supply of gas to respiration air ,can be effected. Investigations of particular interest in this respect are those which comprise

a portion of the inhalation or exhalation cycle,
or exactly one inhalation or exhalation cycle,
or a plurality of inhalation or exhalation cycles.

Claims

1. An apparatus for removing gas from respiration air or for supplying gas to respiration air, comprising a respiration tube (4), a flowmeter (11) which is incorporated therein, and a container for gases which is connected to the respiration tube (4), **characterised in that**
   - the container is formed as a cylinder-and-piston arrangement (1, 2),
   - a servomotor is provided for moving the piston (1)
   - and a controller is provided for operating the servomotor,
   - and operation is effected so that the velocity of the piston is proportional to the throughput measured by the flow meter (11) (volume per unit time).

2. An apparatus for removing/supplying gas according to claim 1, **characterised in that** the chronological starting point and chronological end point of the piston stroke with respect to the commencement of inhalation or exhalation can be predetermined by the controller.

3. An apparatus for removing supplying gas according to claim 1, **characterised in that** the chronological starting point of the piston stroke with respect to the commencement of inhalation or exhalation and the volume conveyed by the piston can be predetermined by the controller.

4. An apparatus for removing/supplying gas according to any one of claims 1 - 3, **characterised in that** the chronological starting point and chronological end point of the piston stroke cover a proportion of the inhalation or exhalation cycle or exactly cover one inhalation or exhalation cycle, or cover a plurality of inhalation or exhalation cycles.

5. An apparatus for removing/supplying gas according to any one of claims 1 - 4, **characterised in that** at least one valve (7, 8) is provided between the cylinder (2) and the respiration tube (4) and enables or shuts off the flow between these two elements.

6. An apparatus for removing/supplying gas according to any one of claims 1 - 5, **characterised in that** an analysis instrument for determining the concentration of the exhalation air conveyed by the piston (1) is connected to the cylinder (2).

7. An apparatus for removing/supplying gas according to any one of claims 1 - 6, **characterised in that** a line (12, 15) for the supply of gases is connected to the respiration tube (4) and/or to the cylinder (2), and the line comprises a valve (13, 17) by which the flow can be enabled or shut off.

8. An apparatus for removing/supplying gas according to any one of claims 1 - 7, **characterised in that** at least two cylinder-and-piston arrangements (1, 2) are connected to the respiration tube (4) and a servomotor is provided in each case for moving each piston (1).